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GEOMORPHOLOGICAL MAP OF THE PO PLAIN, ITALY, AT A SCALE OF 1:250 000

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ABSTRACT

A 1:250 000 scale map of the Po Plain, northern Italy, has been produced by a team of 11 geomorphologists from several Italian universities and other scientific institutions. Their coordinated work in producing the map started in 1986 and was organized through a consortium of 10 local groups. The map provides a detailed classification of landforms based on morphogenetic criteria and has a clear morphographic content together with some morphometric elements. The temporal evolution in regional landform patterns is not directly evidenced by the legend, but may be interpreted through examination of relic surfaces, river beds and beach ridges represented on the map. The map also highlights the effects of human impacts on the evolution of the river system and coastal zone. This paper chronicles the mapping process and presents the geomorphological basis for production of the map itself. It uses extracts from the map to illustrate the major points and provides interested readers with information on how to obtain the complete map. Copyright © 1999 John Wiley & Sons, Ltd.

KEY WORDS: geomorphological map; northern Italy; landform genesis and evolution; drainage pattern; applied geomorphology; Po Plain

INTRODUCTION

In the early 1980s, a number of factors combined to favour a project to produce a geomorphological map of the Po Plain, northern Italy. First, regional geomorphic mapping was promoted by the International Geographical Union through the activities of various commissions that had been on-going since the 1960s (Demek and Embleton, 1978), and through the Working Group on Geomorphology of River and Coastal Plains, chaired by J. ten Cate (1980–1987) and M. Oya (1987–1988). Second, interest in the regional geomorphology of Italy was stimulated by the policy of the Italian Ministry for University and Scientific Research (MURST) in providing funds for scientific projects of national interest. Third, demand for geomorphological information on the part of public administrations was generated by the need to improve their knowledge of land information systems, particularly with reference to many 'fragile' plain areas. Fourth, geomorphologists working at different universities on research concerned with small areas of the plain recognized that they required a regional geomorphological map to provide the wider context within which to compare their study methods and to present results under homogeneous criteria.

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As a result of these imperatives, a co-ordinated plan for medium-scale geomorphological mapping of the entire Po Plain region was initiated in 1986. The authors worked for many years, under three successive national programmes supported by MURST. The project built on the published results of many previous studies of parts of the Po Plain. A list of these previous studies was compiled and published for ease of consultation by Bondesan *et al.* (1995). A separate project to study vertical ground movements in the region was performed by P. Russo at the University of Ferrara. At the conclusion of these projects, the results were combined to support the publication of two large, co-ordinated maps: first the *Geomorphological Map* (MURST, 1997a) and, second, the *Map of Relief and Vertical Movements of the Po Plain* (MURST, 1997b), both at a scale of 1:250 000. Sample extracts from the first map are presented here in Figures 1 and 2.

The Po Plain is a well defined physiographic region. It covers about 47 500 km^2 and ranges in altitude from 650 m in southern Piedmont to -5 m in the Po delta. Lying between two high mountain chains and well supplied with water, the plain has a population of about 20 million people. The region is subject to a series of complex environmental problems that cannot be addressed in isolation, but must be considered within the context of the entire landscape system.

In planning the project, a suitable working method for mapping this densely inhabited region had to be established. Careful identification of the geomorphological elements constituting the landscape system was a necessary first step, and this was achieved by examination of historical cartography and analysis of recent topographical data, together with processing of aerial photographs and satellite images. The area is active tectonically and the dynamics of uplift and subsidence have implications for the landform evolution. A structural map at a scale of 1:2 000 000 and many geological profiles helped in considering the relationships between surface forms and substratum tectonics. Also, people have lived in the region for millennia and their activities have transformed the form and function of parts of this large region, with complex impacts on the geomorphology and landscape. In producing the geomorphological map it was therefore essential to document the effects of tectonics and human activities in affecting geomorphic evolution, particularly along the rivers and coastline.

The end product of the project is a semi-detailed map, which presents an overall view of the regional geomorphology (Castiglioni, 1995; Castiglioni, 1999). The project also supported significant applied research including, for example, the evaluation of aquifer vulnerability (Cavallin and Giuliano, 1992; Bondesan *et al.*, 1994) and the identification of coastal areas vulnerable to storm surges and sea-level rise (Bondesan *et al.*, 1995a).

CONTENT OF THE MAP

Landform classification and analysis

The general criteria used to classify landforms were genetic. These criteria have been described by Castiglioni *et al.* (1990) and that description is not reiterated here. However, a short précis of the criteria is included in order to allow this paper to stand alone.

Landforms are classed as: fluvial and fluvioglacial; glacial; coastal; aeolian; tectonic; and man-made. Different colours are used to distinguish different genetic classes of landform in the map, although colour usage is not entirely rigorous. For example, linear landforms of fluvial or fluvioglacial origin are represented by pure red or halftone red symbols, while violet symbols or lines indicate tectonic and tectonically influenced forms.

Morphography was taken into account in mapping the geomorphology through the representation of single macroforms and mesoforms in scale. Only the smaller landforms are represented by symbols. The predominant surface sediments are mapped by area using appropriate fills and colours. Hence, fluvial and fluvioglacial materials (flat and dotted green colour) are mapped as conglomeratic, gravelly, sandy, silt-clay and, finally, peaty (black dashes). In the coastal zones beach sands are shown in brown, interfingering with the lagoonal sediments of tidal flats (orange) and with fluvial, deltaic sands. Areas covered in weathered materials and loess are represented by combinations of fills in orange, or orange plus violet.

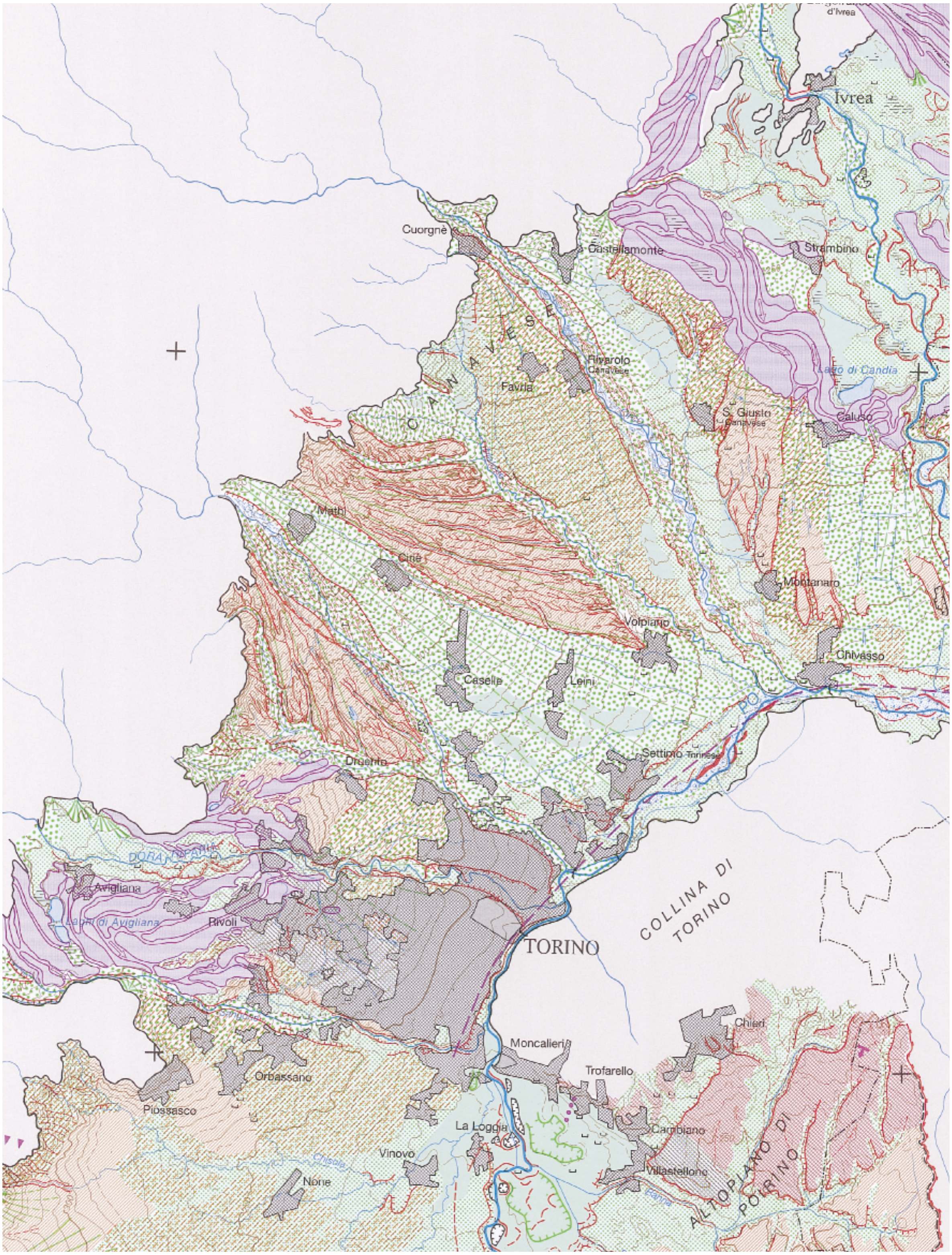

Figure 1. Part of the Piemonte, as represented in the *Geomorphological Map of the Po Plain 1:250,000* reproduced here at 78% of original size. Copyright S.E1.Ca., Firenze, 1997, reproduced with permission

Figure 2. Part of the coastal belt, as represented in the *Geomorphological Map of the Po Plain 1:250,000* reproduced here at 78% of original size. Copyright S.E1.Ca., Firenze, 1997, reproduced with permission

Morphometric information is included in some landform classes. For instance, data may include height classes for terrace scarps and slope classes for alluvial and fluvioglacial fans. Fluvial ridges are mainly represented in a very large class, although some ridges are mapped as particular features because they act as obstacles to surface water drainage and so sub-divide the lowest parts of the alluvial plain into closed or semi-closed basins. Where this is the case, the basins are indicated by green lines along their borders.

An important analytical component of the morphometric and morphographical work was the identification of convex or concave elements in the microrelief of certain landforms. This analysis was preceded by complete revision of existing altimetry for the basin, by means of tracing contour lines by interpolation, on the basis of the new topographic maps produced by regional authorities at scales such as 1:10 000 or 1:5000. Topographic details of selected landforms were compared to features identified in aerial photographs, field surveys and sediment investigations to define the definitive morphological units represented in the printed map.

Relief and its temporal variation

The geomorphological map uses 5 m contours to define relief. These contours are somewhat obscured in the geomorphic map by the textures, fills and symbols used to represent morphogenesis and surface sediments, and they are shown more clearly in the *Map of Relief and Vertical Movements of the Po Plain* (MURST, 1997b). In the lowest part of the plain two supplementary contours have been added, at +2 and −2 m a.s.l. These supplementary contours are especially useful to users who are interested in understanding regional and local drainage patterns and problems in the fluvial and coastal zones. A coloured edition of the relief map for the low-lying, eastern part of the plain has been printed at a scale of 1:500 000 (Bondesan *et al.*, 1995a).

Revision of the altimetry for the region for the first time allowed a reliable estimate of the extent of areas below sea level in the entire Po–Veneto plain to be made. The mapping indicates that the total area below sea level is 2375 km^2. Prior to reclamation for agricultural use, these areas were all marshy or lagoonal. Examination of the map indicates that, as a consequence of drying and shrinkage of soils in reclaimed areas, elevations have decreased and the area of land below sea level has increased. Given the fact that subsidence is on-going, the extent of land below sea level must be considered susceptible to further changes.

The improved understanding of the relief of the Po Plain gained through the studies contributed not only to the geomorphological mapping of the region, but also to local and applied research projects. For example, researchers studying the western sector of the region have used the new relief map to revise their interpretation of the general topographic trend of the plain and reassess the roles of sedimentary and erosional phases in forming the landscape (Ajassa *et al.*, 1990; Cortemiglia and Cortemiglia, 1994). Similarly, careful studies of the improved relief data for the Lombardy plain have supported a new interpretation of the large alluvial fans in that area, which overlap and merge into the so-called 'livello fondamentale della pianura', or basic plain level (Guzzetti *et al.*, 1997). Also, working in an area of uniform terrain near Venice that gently slopes towards the lagoon, Castiglioni (1997) has used contour geometry and the anomalous directions of several small rivers in the new map to detect and tentatively evaluate neotectonic tilting.

Relief mapping dealt not only with current terrain but also with current rates and distributions of vertical movement. Vertical movements of benchmarks along the precise levelling lines measured by the Istituto Geografico Militare, updated to 1990, are clearly marked on the *Map of Relief and Vertical Movements of the Po Plain* (MURST, 1997b). Diagrams and cartograms by Russo, Gatti and Bondesan (MURST, 1997b; Bondesan *et al.*, 1997a,b) show the intensity of vertical movements in the eastern sector of the plain, represented by space and time variations. According to these authors, in certain cases the rate of subsidence is related to the thickness of the poorly coherent, Plio-Quaternary sediments. It is not surprising, therefore, that subsidence is most rapid near the Apennine margin, where sinking of complicated sedimentary structures in front of the mountain chain has produced thicknesses of Plio-Quarternary sediments ranging from 1000 to 8000 m. In the lowest sector of the plain, rates of natural subsidence due to tectonic activity and compaction of recent sediments currently average about 1 mm a^{-1}, with a maximum rate of about 3 mm a^{-1} in the modern Po Delta and near Ravenna (Bondesan, 1989; Bondesan *et al.*, 1995a). However, the above authors also report rapid changes in subsidence rates in areas where extraction of methane or water is, or has been, very active:

for example, in the Po Delta area and near Bologna. Where anthropogenic effects are added to natural subsidence, rates of about 10 cm per year or more are recorded.

Fluvial and fluvioglacial forms of Pleistocene age

Considering the map as a whole, most old and young Pleistocene surfaces are evident as coloured areas, with the graphics indicating the exposure of weathered horizons and the extent of loess cover (see, for example, the map extract in Figure 1). However, when interpreting landscape evolution in the area, it must be remembered that the map does not consider age in landform classification. The relationships between the soils and ages of landforms were previously studied in a map of the central sector of the plain produced by Cremaschi (1987), but such analysis has not yet been extended to the entire plain.

Ancient morphological features on aggradational surfaces that are genetically linked to glacial phases may be used to characterize the clearly different 'styles' of morphogenesis associated with the Pliestocene and the Holocene (Sorbini *et al.,* 1984), especially where the surface is directly related to morainic structures. Features that may be used in this way include ancient meltwater channels, fluvioglacial fans and large outwash plains with traces of channels and levees, the patterns of which change gradually from braided to meandering with distance downstream (Marchetti, 1992). The oldest Pleistocene surfaces preserved in the landscape feature significant complexes of landforms including, particularly, those generated by dissection (see Figure 1).

Neotectonics have affected both the ancient terraces situated in marginal zones of the plain near the mountain borders, and the isolated terraces and hills upstanding in the central region. The forms of these terraces and hills reveal the continuing influence of buried structures belonging not only to the Apennine and Alpine systems but also, in some cases, to the Dinaric system.

Holocene and recent evolution of river systems

The river system evident on the map results from dynamic adjustments driven by natural processes and morphological response to the impacts of human activities.

The prehistoric evolution of the river system during the Holocene occurred in response to:

(i) climatic change and sea-level rise;
(ii) entrenching of the main rivers into the inherited Pleistocene surfaces of the piedmont zone and the evolution of the so-called 'Holocene valleys' with their meander belts;
(iii) tectonic movements, which have influenced river profile readjustments; and
(iv) subsidence and the subsequent tendency of the rivers to aggrade in their middle and low courses.

Notable morphological features and landforms that have resulted from Holocene river evolution include alluvial fans, natural levees, extensive crevasse splay deposits and abandoned channels left by river avulsions (see Figure 2, in which many fluvial ridges, represented by halftone red belts, can be identified).

During historic times, river channel dynamics, as well as coastal evolution, have influenced the history of human settlement in the area, while humans have, in turn, played an active role in modifying the fluvial processes and landforms. Historically, the policies of the former Republic of Venice in diverting rivers far from the lagoon are famous in this regard, but numerous artificially diverted or canalized rivers may, in fact, be found throughout the Po plain. Flood control remains one of the main problems facing central government and local authorities. Consequently, engineering works to control flooding continue to impact channel locations and morphologies throughout the area.

Research using historical maps and aerial photos to chronicle recent morphological evolution of the Po and other rivers highlights changes in planform pattern, while repeat channel surveys reveal increasing rates of sedimentation between the levees built for flood defence. Over the last few centuries, sedimentation has given rise to many rivers becoming 'suspended'–that is, the elevation of their channel bed significantly exceeds that of the surrounding floodplain. However, many reaches have exhibited rapid degradation in recent decades due to the intentional impacts of channel training and unintentional response to gravel mining. Both forms of

relatively short-term evolutionary trend are indicated on the map. Detailed studies of the morphological evolution of the Po include work by Govi and Maraga (1993), Dutto and Maraga (1994) and Castaldini and Piacente (1995).

Coastal evolution

The map establishes the extent and pattern of ancient buried and outcropping beach ridges inland from the present-day Po Delta and it supplies further information regarding long-term coastal evolution, by identifying ancient lagoonal inlets, the presence of active and inactive lagoon deltas, and traces of ancient lagoon channels. Further evidence on long-term evolution may be drawn from recent stratigraphical studies (Marocco, 1991; Bondesan *et al.*, 1995b).

Seawards, several younger beach ridges and dune alignments, intercalated by lagoons or reclaimed depressions, define a complex of cuspate deltas that has been created through evolution of the various branches of the Po itself (see Figure 2). The map also makes clear the very different morphology of the modern delta, which formed rapidly in less than four centuries and may be considered as a 'problem area' to humankind because of its vulnerability to alteration by fluvial activity, coastal processes and sub-soil instability (Bondesan, 1989).

Along most of the Adriatic coast, including the inlets and lagoons, embankments, jetties and other engineering structures have been constructed to protect agricultural land and human settlements against storm damage and to create or preserve favourable conditions for ports and tourist resorts. The map shows the extent to which these and other human activities have influenced beach evolution (Zunica, 1990) and a special symbol has been used to indicate the 'boundaries of lagoon basins of medieval and modern age' and so differentiate them from older features associated with longer-term evolutionary changes.

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REFERENCES

Ajassa, R., Biancotti, A. and Motta, M. 1990. 'Carta altimetrica dell'alta pianura piemontese', *Atti Accademia delle Scienze di Torino*, Classe di Scienze fisiche, matematiche e naturali, **124**, 29–35.

Bondesan, A., Cavallin, A., Giuliano, G. and Mari, G. M. 1994. 'Regional infiltrability map of the Po and Veneto-Friuli plain', *Memorie di Scienze Geologiche*, **46**, 345–352.

Bondesan, A., Meneghel, M. and Baroni, C. 1995. 'Pubblicazioni sulle pianure italiane realizzate nell'ambito dei gruppi di lavoro per i progetti nazionali del M.P.I. e del MURST su temi geomorfologici', *Memorie della Società Geografica Italiana*, **53**, 397–426.

Bondesan, M. 1989. 'Geomorphological hazards in the Po Delta and adjacent areas', *Supplementi Geografia fisica e Dinamica Quaternaria*, **2**, 23–33.

Bondesan, M., Castiglioni, G. B., Elmi, C., Gabbianelli, G., Marocco, R., Pirazzoli, P. A. and Tomasin, A. 1995a. 'Coastal areas at risk from storm surges and sea-level rise in northeastern Italy', *Journal of Coastal Research*, **11**, 1354–1379.

Bondesan, M., Favero V. and Viñals, M. J. 1995b. 'New evidence on the evolution of the Po-Delta coastal plain during the Holocene', *Quaternary International*, **29/30**, 105–110.

Bondesan, M., Gatti, M. and Russo, P. 1997a. 'Movimenti verticali del suolo nella pianura padana orientale desumibili dai dati I. G. M. fino a tutto il 1990', *Bollettino di Geodesia e Scienze Affini*, **56**, 141–172.

Bondesan, M., Russo, P. and Gatti, M. 1997b. 'Map of the relief and vertical movements of the Po Plain', Abstracts, Fourth International Conference on Geomorphology, *Supplementi Geografia Fisica e Dinamica Quaternaria*, **3**(1), 88–89.

Castaldini, D. and Piacente, S. 1995. 'Channel changes on the Po River, Mantova Province, Northern Italy', in Hickin, E. J. (Ed.), River Geomorphology, Wiley, 193–207.

Castiglioni, G. B. 1995. 'Risultati preliminari del nuovo rilevamento geomorfologico della Pianura Padana'. *Memorie della Società Geografica Italiana*, **53**, 13–72.
Castiglioni, G. B. 1997. 'A tentative evaluation of vertical movements in the alluvial plain near Venice, based on geomorphological evidences', *Atti Istituto Veneto di Scienze, Lettere ed Arti*, Classe di Scienze fisiche, matematiche e naturali, **155** (1996/97), 301–314.
Castiglioni, G. B. 1999. 'Geomorphology of the Po Plain', Proceedings of Fourth International Conference on Geomorphology, *Supplementi Geografia Fisica e Dinamica Quaternaria*, **3**(3), 7–20.
Castiglioni, G. B., Bondesan, M. and Elmi, C. 1990. 'The geomorphological mapping of the Po Plain (Italy), with an example in the area of Ravenna', *Zeitschrift für Geomorphologie*, Suppl.-Band 80, 35–44.
Cavallin, A. and Giuliano, G. 1992. 'A procedure for evaluating aquifer vulnerability on a regional scale using computerized systems, a case study', *ITC Journal* (1992/2), 154–158.
Cortemiglia, F. and Cortemiglia, G. C. 1994. Carta geomorfologica della pianura tortonesealessandrina, Litocoop, Tortona, scale 1:100,000.
Cremaschi, M. 1987. Paleosols and vetusols in the central Po Plain (Northern Italy), a study in Quaternary Geology and Soil Development, Unicopli, Milano, 306 pp.
Demek, J. and Embleton, C. (Eds) 1978. Guide to medium-scale geomorphological mapping, Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 348 pp.
Dutto, F. and Maraga, F. 1994. 'Variazioni idrografiche e condizionamento antropico, esempi in Pianura Padana', *Il Quaternario*, **7**, 381–390.
Govi, M. and Maraga, F. 1993. 'Processi di dinamica fluviale lungo l'asta del Po', *Acqua-Aria*, 575–588.
Guzzetti, F., Marchetti, M. and Reichenbach, P. 1997. 'Large alluvial fans in the north-central Po Plain (Northern Italy)', *Geomorphology*, **18**, 119–136.
Marchetti, M. 1992. Geomorfologia ed evoluzione recente della Pianura Padana centrale a nord del Fiume Po, Doctoral thesis, University of Milano, Dipartimento Scienze della Terra, 164 pp.
Marocco, R. 1991. 'Evoluzione tardopleistocenica-olocenica del delta del F. Tagliamento e delle lagune di Marano e Grado (Golfo di Trieste)', *Il Quaternario*, **4**, 223–232.
MURST 1997a. Carta geomorfologica della Pianura Padana / Geomorphological map of Po Plain, S.El.Ca., Firenze, 3 sheets, scale 1:250 000.
MURST 1997b. Carta Altimetrica e dei movimenti verticali del suolo della Pianura Padana / Map of relief and vertical movements of Po plain, S.El.Ca., Firenze, 3 sheets, scale 1:250 000.
Sorbini, L., Accorsi, C. A., Badini Mazzanti, M., Forlani, L., Gandini, F., Meneghel, M., Rigoni, A. and Sommaruga, M. 1984. 'Geologia e geomorfologia di una porzione della pianura a sud-est di Verona', *Memorie del Museo Civico di Storia Naturale di Verona*, **2**, s. II, sez. Science della Terra, 1–92.
Zunica, M. 1990. 'Beach behavior and defences along the Lido di Jesolo, Gulf of Venice, Italy', *Journal of Coastal Research*, **6**, 709–719.

